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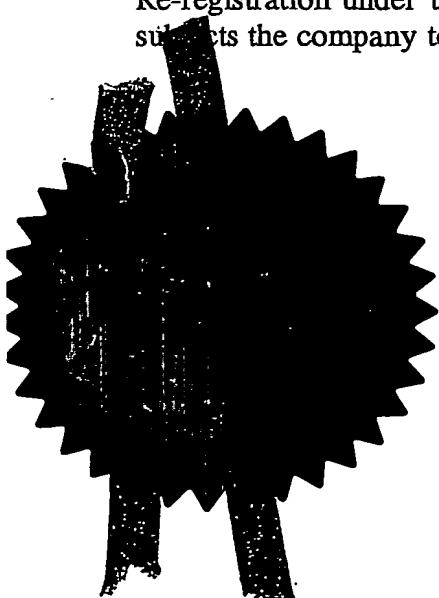
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Dated 12 March 2003

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GB 0207396.3

By virtue of a direction given under Section 30 of the Patents Act 1977, the application is proceeding in the name of

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Incorporated in the United Kingdom,

[ADP No. 08474314001]

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## Request for grant of a patent

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28 MAR 2002

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Concept House  
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1. Your reference

MJD/59124/000

2. Patent application number

30MAR02 E707498-4 D02892

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0207396.3

P01/7700 0.00-0207396.3

3. Full name, address and postcode of the or of each applicant (*underline all surnames*)BG Intellectual Property Limited  
100 Thames Valley Park Drive  
Reading, Berkshire.  
RG6 1PT  
GBPatents ADP number (*if you know it*)

If the applicant is a corporate body, give the country/state of its incorporation

GB

8201725001

4. Title of the invention

A Power Distribution/Generation System

5. Name of your agent (*if you have one*)

BOULT WADE TENNANT

"Address for service" in the United Kingdom  
to which all correspondence should be sent  
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42001

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Country

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Number of earlier application

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Description 17

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Abstract

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Statement of inventorship and right to grant of a patent (*Patents Form 7/77*)

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11

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Date

*B. Wade Tenant* 28 March 2002

12. Name and daytime telephone number of person to contact in the United Kingdom

Martyn J. Draper  
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A POWER DISTRIBUTION/GENERATION SYSTEM

The present invention relates to a power distribution/generation system for supplying 5 electrical power to a number of sites.

Currently the electricity system in many countries relies on large power stations feeding a national transmission network, and thereby providing 10 electricity for homes, commercial properties, industrial premises, and any other consumers. This arrangement means that power is often transmitted across significant distances, with resulting losses in the system. There are also considerable maintenance 15 costs involved in such large transmission network, and a single failure can cause a great deal of inconvenience to a large number of consumers. In addition, the building of new power stations is often opposed due to environmental concerns, especially 20 locally, where the power generated is not necessarily to be consumed close to its source. Distributed generators are currently in use by large consumers of electricity, and some of these are chp (combined heat and power) units. The heat produced during the 25 generation of electricity in these generators can then be used locally for heating (water/space/industrial processes). This heat is a waste product when it is produced at a large power station as there is no local use for it, and the efficiency of the generation is 30 therefore significantly lower than for the distributed generators.

Currently each distributed chp unit operates independently, matching the electricity and heat loads 35 and importing/dumping energy as required to achieve this. Imported power will generally be higher cost than that generated on site, and the dumping of power.

represents waste, resulting in increased energy costs.

According to a first aspect of the present invention there is provided a power distribution/generation system for supplying electrical power to a number of sites, at least some of the sites comprising a generator, at least some of which are Stirling engines capable of generating electrical power, the generators being linked together on a local network, the local network being connectable to an external power grid, and a controller to control the distribution of power so that a site is supplied with electrical power from the local network if its demand exceeds the power generated by its generators, and so that power is drawn from the grid if the total power demand of all of the sites exceeds the power generated by all of the generators.

In the local network, it is likely that one member will need to import electricity, while another has spare electrical capacity. By combining multiple sites in this way, it is possible to match the overall demand more closely and hence waste less energy or import less high-cost electricity from the grid giving increased environmental and economic benefits.

The applicant's current proposal is to use a Stirling engine as the combined heat and power unit. More particularly, our preference is for a linear free piston Stirling engine as this is able to operate as a combined heat and power unit quietly, efficiently and with acceptably low maintenance costs. In addition this is a synchronous machine where the speed of reciprocation, and therefore the frequency of the power generated, is constant.

A network of such generators would have the advantage that each Stirling engine generator would automatically match the output frequency of the power it generates to that of the network. No external 5 synchronising circuitry is then required to maintain a smooth waveform across the network. This would give superior power quality when compared with a network that uses predominantly an alternative design of generator, and minimise the potential for abnormal 10 operation in installed domestic equipment incorporating waveform-sensitive timing circuitry.

The controller is preferably arranged to export excess power to the grid if the power generated 15 exceeds the power demand of the local network. Thus, if it is economically favourable, the generators may be run to produce excess power for export. In the case of a combined heat and power unit this will generally be run to supply some, if not all, of the 20 heat requirement for a site. Thus, at times of high heat demand and low power demand on the local network, excess power will be available for export, giving a potential economic benefit to network members.

If the economic conditions favour it, it may be preferable for the controller to be arranged to 25 operate the combined heat and power unit to produce a power output to match, as far as possible, the power requirement of the local network. In other words, under these conditions, as much of the electrical 30 power requirement as possible is supplied from the generators of the local network, rather than from the external grid. Depending upon the demand in the various sites, this may result in certain combined 35 heat and power units being required to dump heat.

The connection between the local network and the

grid may be implemented by each generator being individually linked to the grid. The requirements of the local network would, of course, also require the generators to be linked together to allow the distribution of power within the local network.

5 However, preferably, all of the generators in the local network are routed through a hub which is then connected to the grid, as this avoids duplication of essential equipment required to connect to the grid.

10 Domestic heating systems conventionally require a supply of electrical power to power their control and ignition systems in order to operate. Therefore, during a power cut, not only do dwellings lose their  
15 electrical power supply, but they also lose their heating system. The system of the present invention is therefore preferably provided with means to detect the absence of mains power, wherein the controller is arranged to operate in the absence of mains power to supply electrical power to selected electricity consuming apparatus. As a priority, this electrical power should be supplied to the essential systems required to operate the combined heat and power systems to guarantee the consumer's heating system in  
20 the event of a power cut. This grid independent operation is the subject of our co-pending application no. 0130530.9

Under these grid independent conditions, the  
30 system can be arranged either to supply power to a dedicated emergency circuit in which case the power demand can be suitably limited. Alternatively, power may be selectively supplied to certain designated emergency sockets within a site. Under these circumstances, the power demand from the local network  
35 is in the hands of the consumer. If excess power is demanded, this could damage the combined heat and

power unit. Such damage may be prevented by a simple protection device (e.g. a fuse) to isolate the generators if excess power is demanded. However, preferably, the system comprises means to detect 5 excess power demand, and to trim the peak voltage supplied to the selected sockets for a predetermined period of time. This voltage is trimmed to a level at which it will not damage sensitive equipment. However, it should be sufficient to provide a 10 noticeable deterioration in the performance of the equipment, thereby alerting the consumer to the excess power demand and providing them with the opportunity to reduce this power demand. If the power demand is exceeded for longer than the predetermined period or 15 if the power demand is increased further, the system is preferably provided with means to isolate the generators. Thus, if users fail to heed the excess power warning, ultimately the power to the selected components will be cut. However, the system can be 20 arranged to restart following such a power cut once the demanded power load has been reduced.

In order for the generators in the local network to communicate with the controller, some form of 25 communication is required from each generator to the controller. This may be done along a dedicated control network. However, preferably, the cables which carry the power to and from each site are also used as a carrier for the communication signals 30 between the sites. Such technology is known in the art, for example, from US 4,641,322.

The present invention also extends to a method for supplying electrical power to a number of sites 35 using a system according to the first aspect of the present invention, the method comprising the steps of monitoring the power generated by each generator,

monitoring the power demand at each site, and  
controlling the distribution of power so that a site  
is supplied with electrical power from the local  
network if its demand exceeds the power generated by  
5 its generator, and drawing power from the grid if the  
total power demand of all of the sites exceeds the  
power generated by all of the generators.

10 An example of a system in accordance with the  
present invention will now be described with reference  
to the accompanying drawings, in which:

15 Fig. 1 is a schematic diagram of a Stirling engine system providing an individual combined heat  
and power unit for use in the system of the present  
invention;

20 Fig. 2 is a set of graphs of power against time  
showing the power demand for a number of dwellings,  
and the total power demand of these dwellings as a  
function of time; and

Fig. 3 is a schematic view of an overall system  
according to the present invention.

25

#### Stirling Engine

30 The system preferably comprises a number of  
domestic combined heat and power (dchp) units as shown  
in Fig. 1. Each unit is based around a Stirling  
engine 1. The engine is preferably a linear free  
piston Stirling engine the operation of which is well  
known in the art. For use in a dchp system, the  
electrical output of the engine should be a single  
35 phase output of less than or equal to 16A.

The Stirling engine 1 is driven by a heat input

from engine burner 2. This burner is fuelled by combustible fuel supply 3 which is mixed with an air supply 4 under the control of a valve 5. The fuel may be a combustible gas such as natural gas, LPG LNG or biogas. Alternatively, liquid fuel may be used.

5 These fuels can also be used if the generator is something other than a Stirling engine. The mixed stream is fed to the burner 2 by a fan 6. This drives the Stirling engine in a manner well known in the art

10 to generate an electrical output 7 from a linear alternator. Heat is extracted from the Stirling engine at cooler 8 which is essentially a heat exchanger through which water is pumped by a pump 9 along line 10. The water passing through the cooler 8

15 is then further heated in a heat exchanger 11 by exhaust gas from the engine burner which has heated the head of the Stirling engine. In order to provide further heating of the water, and to provide a degree of independence to heat the water when the Stirling

20 engine is not being operated, a supplementary burner 12 is provided to heat the water in the heat exchanger 11. The supplementary burner is fuelled by a combustible gas supply 13 which is mixed with an air supply 14 under the control of a valve 15. The mixed

25 stream is fed to the supplementary burner 12 by a fan 16.

Exhaust gases from the engine burner 2 and supplementary burner 12 which have given up their heat in the heat exchanger 11 then exit along flue 17. In this manner, the Stirling engine 1 produces an electrical output 7 and a heat output 18 which may be used, for example, to provide the domestic hot water requirement, or to feed a central heating system.

35

Introduction to Overall System

The local network of the present invention provides a way of connecting together multiple generators such as the dchp unit described above, along with other domestic power consumers and distributed generators. This allows the local network to smooth the overall supply and demand profiles illustrated in Fig. 2. Here the power demand profiles within five separate dwellings ( $P_1$  to  $P_5$ ) are combined to give a smoother overall curve ( $\Sigma P$ ). The network can therefore use the combined power requirements and the total network generating capacity to balance out the needs between the network members.

An example of a system in accordance with the present invention will now be described with reference to Fig. 3.

In broad terms, Fig. 3 is divided by line 30 into the grid 31 and its associated control circuitry shown above line 30, and the local network shown below the line 30. The local network consists of a number of sites, three types of which are shown schematically in Fig. 3. There may be any number of each of these types of dwelling in a particular local network. The first type of site 32 has a combined heat and power system and is configured both to have the capability to both import and export external power. The second type of site 33 is a consumer only unit with no generating capability and, as such, is typical of a present day dwelling. The third type of site 34 is a supplier only which exports power, but has no import requirement.

#### Grid System

The grid 31 and its associated circuitry will now be described. The hub interface is controlled under

the action of hub controller 35. In fact, this controller 35 is responsible for regulating the distribution of power within the local network 35 and, as such, is as much a part of the local network as a 5 part of the grid control system. Mains power from the grid 31 is connected into the controller via a system of protective devices including a main fuse 36 which provides ultimate protection for the local network. This will be of a rating suitable for the local 10 distribution network. A hub meter 37 measures the import and export of power between the local network and the grid, allowing payment to be made as appropriate. Further grid protection is provided by hub grid protection control 38, hub grid isolation 39 15 and hub voltage controller 40. The hub grid protection control 38 monitors the voltage and frequency of the mains supply from the grid. This is described in greater detail in our earlier application GB 0102212.8. The hub grid isolation module 39 receives a "mains healthy/mains not healthy" signal 20 from the hub grid protection control 38. It then acts either to maintain the mains link, or to isolate the local network, via a relay, if the mains supply is assessed to be of poor quality or to be absent. The 25 hub voltage controller 40 comes into operation when the local network is isolated from the grid, when the hub controller 39 can no longer use the grid as a power sink for excess generating capacity. The hub voltage controller 40 is linked to the hub controller, so that excess power can be controlled. This 30 maintains the voltage within the local network within preset limits.

Sites of Local Network

35

The first type of site 32 has a dchp unit having an alternator, Stirling engine burner 2, supplementary

burner 3 and heat exchanger 11 as shown in Fig. 1 to produce a heat output 18 to satisfy a domestic heat load 41 and an electrical power output 7. This is passed through a start/synchronous stop unit 42 via a  
5 fuse/manual isolator unit 43 which isolates the dchp unit from the power consuming appliances to a consumer unit 44. This consumer unit 44 also receives power from the grid hub controller 35, a mains communication unit 45 which monitors the state of the grid, via a  
10 conventional fuse 46 and a meter 47. From the consumer unit 44, the domestic loads 48 are supplied.  
-----  
This whole system is operated by a dchp unit controller 49 as described below.

15 The second type of site 33 is a consumer only site having a conventional fuse 50 and meter 51 and a consumer unit 52 from which a number of domestic loads (not shown) are supplied.

20 The third type of site 34 is a supplier only. This comprises a generator 53 which may supply power to local loads, and which can export power via a manual isolator 54, meter 55, fuse 56 and mains communication unit 57 under the operational controller  
25 58.

#### System Operation

30 The operation of the system will now be described.

The hub controller 35 monitors the voltage and current of the local network and signals the individual members to adjust their power outputs so as  
35 to maintain the local network voltage within preset limits (230V ± 10%). For example, if the operator is a Stirling engine as described, this is achieved by

continuous transmittal of signals from the units informing the hub of the Stirling engine burner 2 setting (-1:Off, 0: modulating +1: full) at any time. The hub controller 35 will return a + 1, 0 or -1 signal to indicate that the burner output should be increased, stay the same, or reduced by a preset increment. In this way the individual dchp unit power outputs are adjusted to suit the network demand at any time.

10

If a -1 signal continues to be sent to the hub controller 35, despite continued requests for an increase in burner output, the hub will interpret this as a burner fault. A service visit to this dchp unit 15 will then be initiated automatically. This will not cause any inconvenience to the consumer concerned, as the remaining network capacity will continue to feed this dwelling until the fault can be rectified.

20

If a +1 signal continues to be sent to the hub controller 35, despite continued requests for a decrease in burner output, the hub will interpret this as a local heat demand in excess of that which would be produced at the requested burner setting. In this cause the hub controller 35 will allow the dchp unit 1 25 to maintain excess generating output. As long as the dwelling is connected to the network this power will flow onto the network, and the hub controller 35 will operate to allow another consumer to make use of it, 30 export it to the grid, or dissipate it via the hub voltage controller 40.

35

If the local heat demand is insufficient to dispose of all of the heat produced at the requested burner setting, the dchp unit 1 will initiate heat disposal using the fan 16 for the inactive supplementary burner 12 to blow cool air into the heat

exchanger 11.

Power Maximisation (Voltage reduction)

5 Where the power demanded by the local network increases to exceed the maximum generating capacity of the network, the hub controller 35 will normally monitor the import of additional power from the Grid, via the hub meter 37. If the mains connection is not  
10 present and the network is operating independently, the available power will be maximised by using a voltage waveform reduction technique as the current increases within the network, to maintain the power output within the generating capability of the local  
15 network. The voltage can be reduced by 10-15%, depending on the type of equipment involved, with minimal effects. The visible effects of the voltage reduction act as a warning to the consumers that no additional equipment should be connected to the  
20 network until, either the power demand reduces naturally, or until mains power is available to import. The larger the network is, the less likely this is to occur, as the average consumption at any time is less likely to exceed the total generating  
25 capacity.

Grid Reconnection

Under mains failure conditions, once the mains  
30 link is disconnected, the hub grid isolation module 39 waits until the hub grid protection control 38 sends a mains healthy signal once more. As the network voltage will be unsynchronised with the mains after a period of independent operation, this reconnection may necessitate that the generators be shut down and  
35 restarted once the grid supply has been reconnected. To minimise inconvenience to the users, this would be

undertaken once the power demand is minimal. The hub controller 35 would determine the best time for this, waiting until the demand drops below a preset level, generally during the night. Alternatively,

5 resynchronisation of the operating generator's may be carried out without a shutdown and restart. This can be achieved by monitoring the network and grid waveforms and appropriately controlling the reconnection as they coincide.

10

After a 3 minute period of healthy mains supply it can be reconnected to the local network. All generators connected to the local network will be shut down, and the grid supply will be reconnected at the 15 hub grid isolation module 39. Power will therefore be restored to the sites almost instantaneously. The dchp units 1 will wait until the Stirling engine burners have cooled sufficiently to allow a restart. Other generators will have similar safe restart 20 periods, after which they can resume generation. The hub controller 35 will then restore the balance across the network.

Communication between Sites

25

In order for the systems of each site 32-34 to be combined, some form of communication is needed between them. The mains cables used to transmit the power across the local network can also be used as a carrier 30 for the communication signals. Such technology is known and easily adapted for this purpose.

35

Each exporting site 32,34 has a mains communication unit 45,57 connected at the network link. This receives signals from the controllers 49,58 for the individual generators, and sends and receives all trimming signals to and from the hub

controller 35.

Where the site 32 has a dchp unit 1, the mains communication unit 45 receives signals from the dchp unit controller 49 relating to the Stirling engine burner setting (-1:off, 0: modulating, +1: full) at any time. This is converted to the appropriate signal and transmitted to the hub controller 35 via the mains cables. The hub will return a +1, 0 or -1 signal to indicate that the burner output should be increased, stay the same, or reduced by a preset increment. The mains communication unit interprets this signal and informed the dchp unit controller so that, heat demand permitting, the Stirling engine burner can be adjusted accordingly. In this way the individual dchp unit power outputs are adjusted to suit the network demand at any time.

Similarly, where the site 35 has a distributed generator 53 the mains communication unit 57 receives a signal from the hub controller specifying whether the power generated should be increased (+1), stay the same (0), or reduced (-1). This will be conveyed to the controller 58 operating the distributed generator, which will return a signal indicating the current status of the generator (-1: off, 0: modulating; +1: full) at any time. This is converted to the appropriate signal and transmitted to the hub controller 35 via the mains cables.

30

Where a site 33 is a consumer only, there is no generator to adjust, so no trimming signals are sent across the network. The consumer link does not therefore need a mains communication unit, reducing the installation costs, and allowing the connection to be equivalent to the existing mains connection arrangement.

Network Control Strategy (Power led)

The hub controller 35 will always act to minimise excess power for which there is no economic demand  
5 (local use or chargeable export).

- Where power can be exported to the grid 31, the hub controller 35 will trim the network generating capacity to maximise this. Any communication with the central grid control system will take place with the hub controller 35, so that the arrangement can be operated to be beneficial to all concerned. The presence of this hub controller 35 makes the co-operative network into the equivalent of a larger distributed generating plant as far as the grid is concerned.
- Where no benefit will be derived from export, but it is allowed, the hub controller 35 will use the grid 31 as a pure power sink, only using export to maintain the network voltage within the preset limits.
- Where export to the Grid is not allowed the hub controller 35 will import power as required to satisfy excess demand within the network, but will dissipate excess power using the hub voltage controller 40.
- Under grid independence excess power will be dissipated through the hub voltage controller 40, but no import will be possible. The hub controller 35 will then be responsible for maintaining the voltage level within the network by trimming the generators as appropriate.

The control strategy used by the hub controller is therefore based on the power demand within the local network, whereas the control strategy within each site 32 is heat led. The individual units send regular signals to the hub informing of the power output generated at any time (via the Stirling engine burner setting signal or a power meter in the control system). The hub controller 35 then acts to either increase the power fed onto the local network by increasing the individual generator outputs, reduce it by decreasing the individual generator outputs, or maintain the status quo. The individual generators are responsible for dissipating any excess heat produced while generating at the required level, but can feed any excess power, generated in the process of satisfying the local heat demand, onto the network where the hub controller 35 will dispose of it.

It is advantageous to keep as many units as possible generating at any time, so that when a sudden increase in power demand occurs, this can be quickly satisfied by first increasing the power output from the active units. Other units can then be switched on and the load balanced between them over the course of a few minutes. The overall system then becomes more responsive to consumer demand than it is possible for a single unit to be.

Even with a network consisting of the minimum two dchp units, at least one unit will be generating at any time, so that there is sufficient power available for the pumps, control circuitry, etc. (currently around 200W per unit). With larger networks, it is possible to run a number of units at the minimum setting, allowing the power output to be increased quickly when required. The minimum generating output of a dchp unit reflects the power generated when the

engine burner is at its lowest setting (currently 4 kW calorific input to burner), and is around 0.4 kWe.

Fault Currents

5

The fault, or short circuit current for the Stirling engine generator described previously is similar to that from domestic appliances of an equivalent rating (e.g. a 1kW vacuum cleaner), due to 10 the low inertia of the Stirling engine. Suitable protection equipment installed in addition to the fuses 36, 46, 50, 56, provides the required protection should a fault occur.

CLAIMS

1. A power distribution/generation system for supplying electrical power to a number of sites, at least some of the sites comprising a generator, at least some of which are Stirling engines capable of generating electrical power, the generators being linked together on a local network, the local network being connectable to an external power grid, and a controller to control the distribution of power so that a site is supplied with electrical power from the local network if its demand exceeds the power generated by its generators, and so that power is drawn from the grid if the total power demand of all of the sites exceeds the power generated by all of the generators.
2. A system according to claim 1, wherein the Stirling engine is a linear free piston Stirling engine.
3. A system according to any one of the preceding claims, wherein the controller is arranged to export excess power to the grid if the power generated exceeds the power demand of the local network.
4. A system according to any one of the preceding claims, wherein all of the generators in the local network are routed through a hub which is then connected to the grid.
5. A system according to any one of the preceding claims, further comprising means to detect the absence of mains power, wherein the controller is arranged to operate in the absence of mains power to supply electrical power to selected electricity consuming apparatus.

6. A system according to claim 5, wherein the controller is arranged, upon detection of the absence of mains power to selectively supply electrical power to certain designated emergency sockets within a site.

5

7. A system according to claim 6, further comprising means to detect excess power demand, and to trim the peak voltage supplied to the selected sockets for a predetermined period of time.

10

8. A system according to any one of the preceding claims, wherein the cables which carry the power to and from each site are also used as a carrier for the communication signals between the sites.

15

9. A method for supplying electrical power to a number of sites using a system according to any one of the preceding claims, the method comprising the steps of monitoring the power generated by each generator, monitoring the power demand at each site, and controlling the distribution of power so that a site is supplied with electrical power from the local network if its demand exceeds the power generated by its generator, and drawing power from the grid if the total power demand of all of the sites exceeds the power generated by all of the generators.

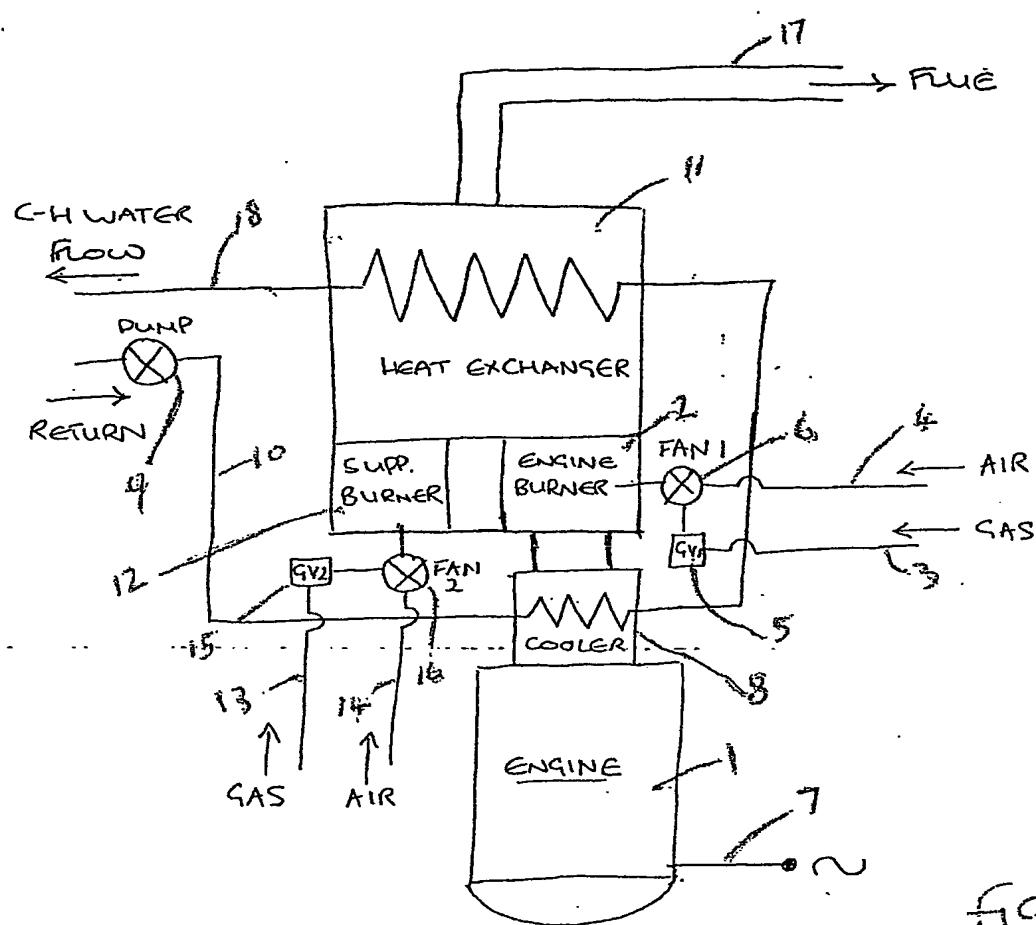


fig 1

Figure 2 – Combined Power Demand Profiles

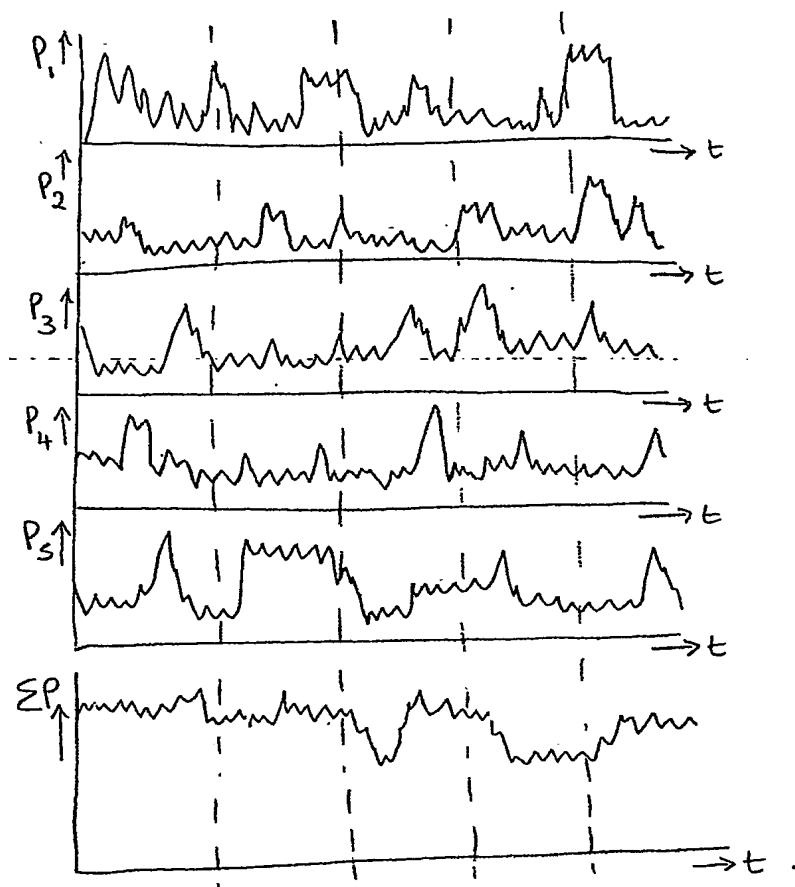
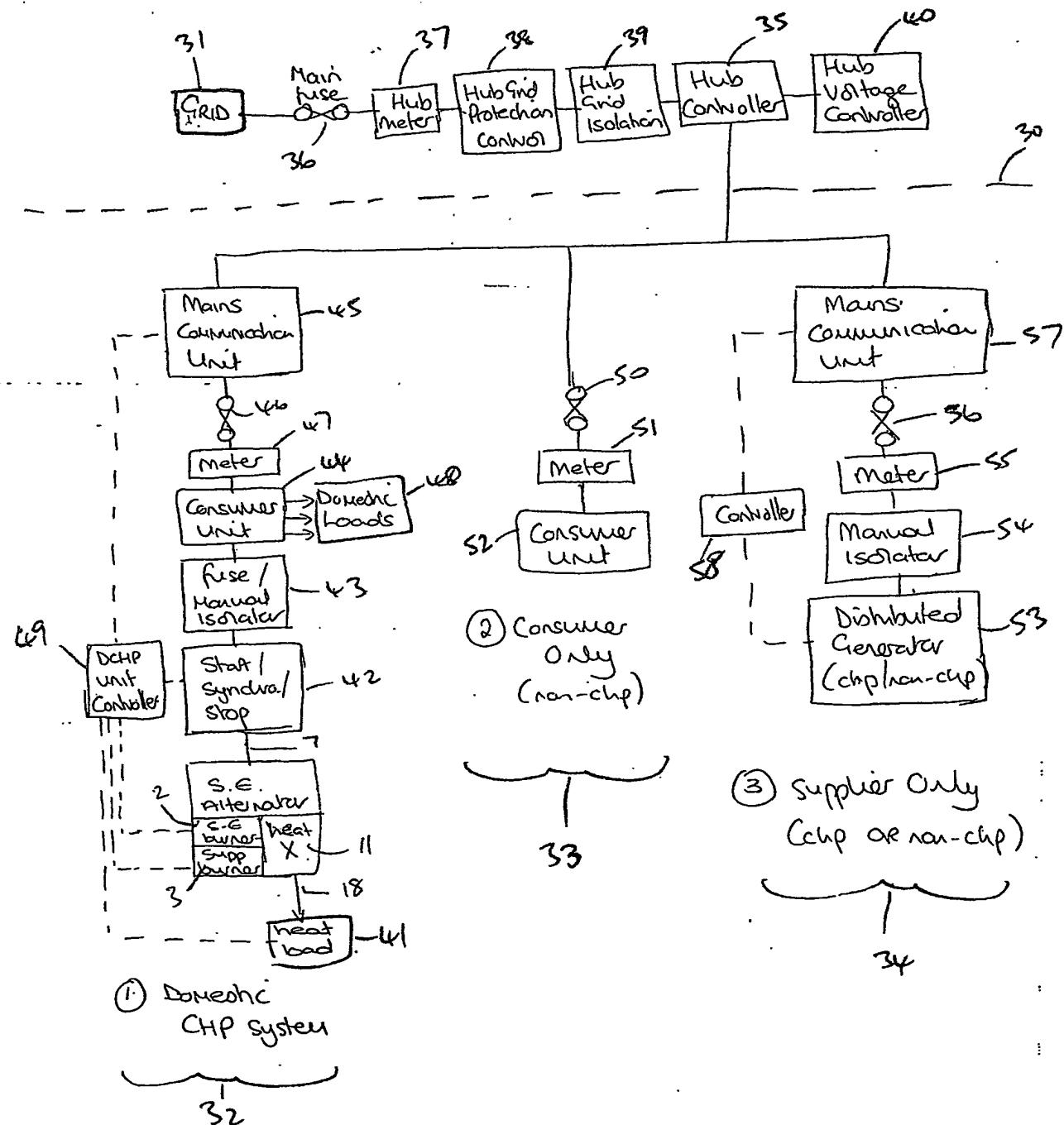


Figure 3 – Co-operating Network connections



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